

# **MULTIFACETED CHALLENGES AND OPPORTUNITIES ASSOCIATED WITH SMALL MODULAR REACTORS IN AFRICA: A *Nonproliferation Perspective***

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## **Abstract**

In response to the increasing global energy demands driven by industrialization and the urgent need for decarbonization, this study explores the potential of Small Modular Reactors (SMRs) as a sustainable energy solution in Africa. With a focus on nonproliferation concerns, the paper assesses Africa's energy landscape, emphasizing the need for diverse and reliable power sources. While highlighting the scalability and cost-effectiveness of SMRs, the analysis acknowledges potential challenges associated with adhering to the Nonproliferation Treaty with their mass deployment in the African continent. Examining regulatory frameworks, international cooperation, and security protocols, the study also underscores the importance of regional collaboration to prevent the misuse of nuclear technology for military and malicious purposes. The economic and geopolitical implications of SMR deployment in Africa are also investigated, considering its contributions to energy security and economic growth. Drawing insights from successful case studies, the paper concludes by synthesizing key findings and proposing recommendations for policymakers and stakeholders. These recommendations encompass regulatory enhancement, capacity building, technology transfer, and diplomatic efforts to strengthen nuclear security, nonproliferation, and safeguards. The overarching aim is to advocate for a balanced approach that maximizes the benefits of SMRs while mitigating associated risks to ultimately contribute to the sustainable and secure development of nuclear energy in Africa.

## **1. INTRODUCTION**

As the global energy landscape undergoes transformative changes, the emergence of Small Modular Reactors (SMRs) in Africa holds immense promise for addressing the continent's pressing energy needs. The rapid population growth and urbanization in Africa have amplified electricity demand, while access to reliable and affordable energy still eludes many regions[1]. While Africa traditionally relies on conventional energy sources, such as fossil fuels and hydroelectric power, SMRs offer a promising alternative with their smaller size and modular design, providing scalability to meet varying energy demands. These features make them suitable for both grid-connected and off-grid applications in remote areas. In addition, SMRs incorporate advanced safety features and can be designed with passive cooling systems, offering enhanced safety and environmental benefits compared to traditional large-scale nuclear reactors[2].

In addition, deploying SMRs can stimulate industrial development, create jobs, promote technology transfer, and encourage local manufacturing of reactor components, thus contributing to building a skilled workforce and promoting technological self-sufficiency in the nuclear sector. Additionally, SMRs can significantly mitigate climate change by providing a low-carbon alternative to fossil fuels and improving grid resilience by providing a stable and continuous power supply[3]. SMR projects also have the potential to encourage collaboration among African nations, fostering regional partnerships in the development, deployment, and management of nuclear energy. While the emergence of a new technology offers significant advantages to a growing industry, its

impending risks cannot be overlooked. Alongside the potential benefits of clean and scalable energy production, it is imperative to highlight the critical perspectives of nuclear security and nonproliferation in deploying these advanced nuclear technologies. Ensuring safety and security, as well as focusing on the nonproliferation obligation of countries associated with SMR is crucial[4]. Collaborative efforts are required to establish frameworks that address security concerns, promote information sharing, and foster transparency among nations involved in SMR initiatives. Owing to the limited operational history of SMRs globally, a proactive approach to nuclear security is essential, while drawing on insights from past nuclear incidents and accidents to contribute significantly to the secure utilization of SMRs in Africa is paramount[5] [6]. In this regard, SMRs in Africa have significant potential to address the continent's energy challenges, promote sustainable development, and contribute to global efforts to combat climate change. Integrating critical perspectives into the discourse surrounding SMRs, including nuclear security and nonproliferation imperatives can lay the foundation for a responsible and secure nuclear future for the continent and the global community.

## 2. NUCLEAR NONPROLIFERATION

The transfer of nuclear weapons, nuclear weapons technology, or fissile material to nations that do not currently possess them is known as nuclear proliferation. The phrase is also used to discuss the potential for terrorist groups or other armed groups to get nuclear weapons[5].

The leading international initiative to stop the proliferation of nuclear weapons, to further nuclear disarmament and general and complete disarmament, and to encourage collaboration in the peaceful uses of nuclear energy is the Treaty on the Nonproliferation of nuclear weapons (NPT). The NPT became operative on March 5, 1970, having been made available for signature in 1968. The Treaty's duration was indeterminate on May 11, 1995. The Treaty on nuclear nonproliferation, peaceful uses of nuclear energy, and disarmament is the most extensively acknowledged by the 191 States party. States adhering to the NPT that do not possess nuclear weapons have pledged to refrain from producing or obtaining nuclear weapons or other nuclear explosive devices. Conversely, states that possess nuclear weapons have pledged not to aid, incite, or coerce any state that does not possess nuclear weapons in any manner when it comes to producing or obtaining nuclear weapons or other nuclear explosive devices. Nuclear weapon States parties under the Treaty are those that, prior to January 1, 1967, created and detonated a nuclear weapon or other nuclear explosive device. The Treaty's participants include five states with nuclear weapons[7].

Despite not being a party to the NPT, the Treaty assigns the IAEA essential verification duties. For the IAEA to verify that all non-nuclear-weapon State parties have fulfilled their obligation under the Treaty to prevent the diversion of nuclear energy from peaceful uses to nuclear weapons or other nuclear explosive devices, each State party is required under Article III of the NPT to conclude a comprehensive safeguards agreement (CSA) with the IAEA. The Treaty is a fundamental component of the international nuclear nonproliferation framework and lays the groundwork for pursuing nuclear disarmament. It was intended to stop the spread of nuclear weapons, advance the objectives of general and comprehensive disarmament and nuclear disarmament, and encourage collaboration in the peaceful applications of nuclear materials. Under the supervision of the International Atomic Energy Agency (IAEA), the Treaty established a safeguards system aimed at promoting nonproliferation and fostering confidence among States parties. The IAEA employs safeguards to undertake inspections to verify compliance with the Treaty. The Treaty encourages equal access to peaceful nuclear technology and collaboration for all states' parties. Safeguards also stop fissile material from being diverted for use in weapons. Under the auspices of the International Atomic Energy Agency (IAEA), the Treaty established a safeguards system to promote nonproliferation and foster confidence among States parties. The IAEA uses safeguards to undertake inspections to confirm conformity with the Treaty. The Treaty encourages equal access to peaceful nuclear technology for all States parties and collaboration. Safeguards also stop fissile material from being diverted for use in weapons[8].

Together with the five nuclear-weapon States, 191 states have ratified the Treaty. The Treaty's importance indicates that more nations have ratified the NPT than any previous arms control and disarmament accord. Niger (2017), Cape Verde (2020), Morocco (2022), and the Democratic Republic of the Congo (2022) are the African states that have signed the Treaty of Pelindaba since the 9th NPT review conference in 2015, increasing the total number of States Parties to 44[9].

### 3. MEASURES TO ENSURE ADHERENCE TO THE NONPROLIFERATION TREATY

The 191 parties to the nonproliferation treaty are obliged to abide by the following agreements with the IAEA to oversee its success in regulating weapon manufacture, usage, and supply:

#### *3.1 Safeguards Agreements*

The IAEA and the non-nuclear-weapon States Parties to the NPT have legal arrangements known as safeguards agreements, which ensure that the parties do not transfer nuclear material or activities for military use. Despite not being a signatory to the NPT, the IAEA performs verification duties by the agreement. Article III of the NPT mandates that every non-nuclear-weapon State party enter into a comprehensive safeguards agreement (CSA) with the IAEA. This is necessary to allow the IAEA to confirm that each State party is complying with its obligation under the Treaty to prevent the diversion of nuclear energy from peaceful uses to nuclear weapons or other nuclear explosive devices[10, 11].

#### *3.2 Additional Protocols*

The IAEA is given greater access to data and sites through these voluntary agreements, ensuring that no nuclear material or activity in the NPT States Parties has been disclosed. Three non-NPT parties, India, Pakistan, and Israel have implemented safeguards based on item-specific agreements with the IAEA. Under these agreements, the IAEA implements safeguards to guarantee that nuclear material, facilities, and other items covered by the agreement are used only for peaceful purposes and not to produce nuclear explosive devices or for the development of nuclear weapons or other military objectives[12, 13].

#### *3.3 Nuclear-Weapon-Free Zones*

The NWFZ are regional treaties that prohibit developing, testing, or deploying nuclear weapons in certain areas and require the NPT nuclear-weapon states parties to respect and support these zones. These prohibitions are based on treaties that commit signatories to international verification, control, and compliance systems. Five such zones exist today, four spanning the entire southern hemisphere. The regions currently covered under NWFZ agreements include Latin America (the 1967 treaty of Tlatelolco), the South Pacific (the 1985 treaty of Rarotonga), Southeast Asia (the 1995 treaty of Bangkok), Africa (the 1996 treaty of Pelindaba) and Central Asia (the 2006 treaty of Semipalatinsk)[14].

#### *3.4 Risk Reduction Tools*

These measures aim to prevent or manage conflict and reduce the chances of nuclear escalation, such as communication channels, transparency, and confidence-building measures[15,16].

### 4. LIMITING CHARACTERISTICS OF SMALL MODULAR REACTORS AND THEIR PROLIFERATION POTENTIAL

Small Modular Reactors (SMRs) represent an innovative approach to nuclear energy generation, characterized by their smaller size, modular design, and enhanced safety features. Their adaptability makes them a promising option for addressing energy challenges in various settings, including regions with emerging or developing energy needs[22], [23]. Here's a brief explanation of the key concepts associated with Small Modular Reactors and their potential proliferation risks:

#### *4.1 Modularity and Small-Size Design*

Unlike traditional large-scale nuclear reactors, constructed as single, massive units, SMRs are designed to be smaller and more modular. The term "small" in SMRs refers to their reduced power output compared to traditional reactors. SMRs typically have a capacity of less than 300 megawatts electric (MWe), with some designs even ranging down to a few megawatts. This smaller size offers advantages in terms of cost, construction time, and the ability to deploy in a variety of settings. They can be manufactured in factories and transported to the site in modular components, allowing for a more flexible and scalable approach to nuclear power generation[17].

While the size and modularity of SMRs offer advantages in manufacturing and operational costs, they pose a challenge to monitoring nuclear materials. As a result of the multiple modules monitored by fewer control room operators, proliferators can use the opportunity to distract the attention of monitoring systems to steal nuclear materials from unmonitored modules.

#### *4.2 Enhanced Safety Features*

SMRs often incorporate advanced safety features to mitigate potential risks associated with nuclear energy. These features may include passive cooling systems, inherent safety mechanisms, and simplified designs that reduce the likelihood of accidents. Enhanced safety is a key consideration when addressing public concerns and regulatory requirements. Notwithstanding, the reduction in operator action during abnormal events and the general cut in control room occupancy may interfere with physical monitoring and inspection of fuels that ensure non-diversion of nuclear materials[18].

#### *4.3 Flexibility in Deployment*

SMRs can be deployed in a variety of settings, including both grid-connected and off-grid locations. Their smaller size and modular construction enable deployment in areas with limited infrastructure, making them suitable for regions with diverse energy needs. Owing to the siting flexibility of SMRs, the proximity of the public to the plant site may invite individuals with malicious intent that may steal nuclear materials in bits or bulk for purposes of weaponization. Community members may be contracted to disrupt plant operations through rioting to pave the way for proliferation.

#### *4.4 Cost, Construction, and Deployment:*

The modular construction of SMRs can result in cost savings and shorter construction times compared to traditional reactors. Factory manufacturing of components allows for standardization and quality control, potentially reducing the overall cost of nuclear power projects. Notwithstanding, vendors' offsite construction, fuelling, and refueling of SMRs limits the customer's authority to determine the exact activity within the plant. Vendors with malicious intentions may install monitoring devices in these reactors against national security protocols at the customer's blindside. Information retrieved from remotely monitoring the reactors can serve as a manipulating tool to destabilize a country[19].

#### *4.5 Advanced Fuel Cycles:*

Contrary to the CANDU reactors that utilize natural uranium fuels and traditional reactors that use 3-5% enriched, some SMR designs incorporate advanced fuel cycles high-assay low-enriched uranium (HALEU), which can enhance fuel efficiency. HALEU contains about 5-20% of enriched uranium. The compromise of the traditional fuel enrichment limit to improve fuel efficiency somewhat creates an indication that fuel approval for weapon-grade uranium enrichment is possible. Until today, one of the setbacks of the commercialization of SMRs remains the licensing of HALEU for use as fuel in advanced reactors. Due to the fast-evolving technological innovations in the legitimate use of nuclear, there are currently no clear regulatory frameworks that set boundaries on the extent of innovation that may lead to further uranium enrichment[20], [21].

#### *4.6 Scalability and Potential for Decentralization:*

SMRs offer the potential for decentralized energy generation, allowing for increased energy resilience and grid stability. This characteristic is particularly valuable for regions with dispersed or remote energy demands. Unlike in big cities, nuclear materials in small modular reactors deployed to remote areas are more likely to be diverted due to inadequate security. Additionally, the literacy rate and the public's understanding of nuclear and radioactive materials in these small towns are shallow.

## 5. THE PROLIFERATION RISKS OF MASS DEPLOYMENT OF SMALL MODULAR REACTORS

In addressing the proliferation risks associated with Small Modular Reactors (SMRs) in Africa, it is essential to understand the continent's current energy and security landscape and the urgent need for a secure, safe, and sustainable energy source. The African continent has long been noted for its political instability and poverty. As a continent with the world's largest natural resource deposit and youngest vibrant human resources, it has been plagued with a natural resource curse[24]. Regarding a first-of-a-kind (FOAK) and sensitive industry like the nuclear field, there are various motivations for someone or a group of people to engage in the proliferation of nuclear materials and breach security protocols. However, lessons learned in the past decades of operating conventional nuclear power plants have influenced the adoption of robust safety and security designs and regulatory frameworks in recent reactors. Owing to the insufficient operational history of nuclear power in most parts of Africa, the mass deployment of SMRs tends to put the continent at a significant risk[25]. Although the SMR industry boasts of robust safety designs, it is nearly impossible to ascertain the extent to which a person or a group can divert nuclear materials. Aside from the fact that SMRs are first-of-a-kind, the continent has not invested in solid expertise in the nuclear field to ensure safe and secure operations of nuclear power plants.

The safety and security culture statistics within high-risk industries in Africa can be used to project future power plant operations and management. With over a century of operational history, the mining industry in Africa still experiences security breaches, likewise the oil industry. Historically, it has been noticed that the existence of specific resources tends to become the source of conflict. Community stakeholders resort to violence to claim the attention of their governments for community development. Internal and external groups with malicious intentions tend to take advantage of these protests to steal and loot resources. In 2021, twelve countries experienced external involvement in their domestic conflicts: Burkina Faso (which experienced two internationalized civil conflicts), Burundi, Cameroon, Central Africa Republic, DR Congo (two), Ethiopia, Kenya, Mali (two), Mozambique, Niger (two), Nigeria (two), and Somalia.

Politically motivated conflicts in Africa during elections may be another pathway to proliferation. With the nuclear industry's strong association with national and global politics, it is open knowledge to predict that political opponents will likely hold divergent interests in the nuclear industry. Regardless of the revenue generated from the nuclear industry in a country, the anti-nuclear government may instigate foot soldiers to cause distractions such as accidents, power outages, or thefts and conspiracy theories that may defy the intentions of the pronuclear government, thus making the industry unpopular[26].

The general financial commitment that accompanies reactor deployment is beyond the economy of many African countries. While small modular reactors tend to promise a low-cost energy alternative, other equally critical financial attention is needed in different governance sectors. Due to this situation, African countries interested in deploying small modular reactors will resort to loans and other unfavorable repayment models that will likely minimize their control of the operation and management of the power plants. In this way, foreign operators can maliciously use the continent as a hub to divert nuclear materials from its intended purpose while transferring the risk of non-adherence to the NPT to the host country.

## 6. PROACTIVE MITIGATION STRATEGIES TO CURB THE PROLIFERATION RISKS OF SMALL MODULAR REACTORS IN AFRICA

One of the most important qualities of the nuclear industry has been its preparedness strategies for addressing nuclear incidents and emergencies to ensure public safety and maintain environmental integrity. In terms of nuclear security and nonproliferation, this strategy is not new. However, proactivity becomes effective when there is history of lessons learned. First-of-a-kind technologies to be deployed in Africa, such as small modular reactors, may have challenges with baseline operational history that can inform regulatory frameworks to ensure the safe and intended use of nuclear materials. The following recommendations may be adopted to reduce the motivation to divert nuclear materials from their intended purposes during the operation of small modular reactors.

### *6.1 Strengthening Nuclear Education and Public Awareness*

Developing a robust nuclear educational program to demystify nuclear technology is imperative. This strategy will not only raise awareness but also develop the next generation of nuclear enthusiasts that will enforce peaceful uses of nuclear technology. Nuclear education and public awareness are critical factors in addressing the

proliferation risks of small modular reactors (SMRs) in Africa. According to the IAEA's publication on the African Network for Education in Nuclear Science and Technology (AFRA-NEST), increasing the nuclear literacy and competence of the African population can provide the necessary knowledge and skills for the African people to understand, operate, and regulate SMRs safely and securely[27]. This can also foster a positive attitude and confidence towards nuclear technology and its benefits for the continent. Nuclear education and public awareness can inspire and motivate the young generation and women to pursue careers and leadership roles in the nuclear sector. This can also contribute to Africa's nuclear workforce and industry's diversity, innovation, and sustainability. A highly informed public is likely to protect the cause of peaceful uses of nuclear technology. Research has shown that active participants in crimes most likely lack formal education and are misinformed by conspiracy theories that influence wrongdoing. The motivation to proliferate or be influenced to divert nuclear materials will be reduced with the introduction of nuclear knowledge in basic educational curricula[28].

### *6.2 Strengthen the IAEA safeguards system*

The International Atomic Energy Agency (IAEA) is responsible for verifying the peaceful use of nuclear materials and technologies. However, the IAEA may face challenges applying its safeguards to SMRs, especially transportable, floating, or integrated ones. Therefore, increasing the IAEA's funding, personnel, and technical capacity is crucial to cope with the additional workload and complexity of deploying SMRs in Africa. Moreover, it is essential to facilitate collaboration and communication between the IAEA and the SMR developers and operators to address any gaps or issues that may hinder the effective implementation of safeguards. Additionally, it will enhance regional and international cooperation and dialogue on nuclear issues by facilitating the exchange of information, experiences, and best practices among African countries and other stakeholders on SMR development and deployment. This can also promote transparency, trust, and mutual understanding of the nonproliferation objectives and obligations of the parties involved. Sharing relevant information can also contribute to forming a robust regulatory framework and security culture to minimize incidence[29].

### *6.3. Promote regional and Inter-regional cooperation and transparency*

Regional cooperation and transparency can help build trust and confidence among the African countries interested in or pursuing SMRs. For example, regional organizations such as the African Commission on Nuclear Energy (AFCON) can play a role in facilitating information sharing, joint research, and best practices on SMR safety, security, and nonproliferation. Additionally, regional initiatives such as the African Nuclear-Weapon-Free Zone Treaty (also known as the Pelindaba Treaty) can provide a legal framework and a political commitment to prevent the acquisition or development of nuclear weapons in Africa. Additionally, regional and international cooperation and dialogue on nuclear issues will facilitate the exchange of information, experiences, and best practices among African countries and other stakeholders on SMR development and deployment. This can also promote accountability, trust, and mutual understanding of the nonproliferation objectives and obligations of the parties involved[30]. Collaboration with international regulatory bodies and peer review mechanisms can also bolster the effectiveness of Africa's nuclear regulatory framework. Regulatory agencies can enhance their capacity to address evolving challenges and continuously improve safety standards by sharing best practices, lessons learned, and technical knowledge. Sharing relevant information can also contribute to forming a robust regulatory framework and security culture to minimize incidence.

### *6.4 Adopt proliferation-resistant SMR designs and fuel cycles:*

Some Small Modular Reactors (SMR) designs and fuel cycles may pose higher proliferation risks than others due to various factors. These factors include the enrichment level of the fuel, the frequency of refueling, the accessibility of the fuel, and the amount of spent fuel generated. Consequently, adopting SMR designs and fuel cycles that mitigate these risks is prudent. This can be achieved through the utilization of low-enriched uranium (LEU), implementing extended refueling intervals, employing sealed or inaccessible cores, and minimizing or eliminating reprocessing capabilities. Moreover, it is advisable to establish international or regional fuel supply and disposal arrangements. These arrangements diminish the incentives and opportunities for diversion or misuse of nuclear materials. By fostering collaboration and oversight on a broader scale, such arrangements enhance security and accountability within the nuclear energy landscape[31, 32, 33].

### *6.5 Customer Involvement in the assembling, fueling, refueling, and deployment process*

For most small modular reactors, components and reactor fueling are proposed to be assembled offsite and shipped to the customer. This process is completed without the customer's involvement and verification. To ensure that vendors with malicious intent do not install inappropriate monitoring devices that may breach national security, experts from exporting states should be available at the assembly and reactor fueling site to perform final inspections in the interest of national security. States should consequently include technology transfer in their negotiations with vendors to increase local expertise and knowledge in the plant's normal and abnormal operations. This way, attempts of proliferation can easily be detected.

### *6.6 Adopting favorable investment models*

The rich African states' natural resources can serve as a sound bargaining chip for deploying relatively expensive technologies without compromising the safety and security of its members. African states need to reassess the global market demand for abundant natural resource deposits on the continent and price them fairly at globally accepted prices. The ancient method of butter trading can be included in the vendor bidding process. For example, Nigeria, which has Africa's largest oil reserve, can bargain with South Korea on the basis of exporting oil for a specified number of years in exchange for a small modular reactor technology based on the total cost. This way, high-interest rate loans will be avoided, and both parties will exercise purchasing equal rights[34].

### *6.7 Ensuring Independent Regulatory Framework*

Over the years, the nuclear industry has remained the most highly politicized field globally. Developing a robust and independent regulatory framework is paramount for fostering trust and ensuring safety within the nuclear industry, particularly in regions like Africa, where political dynamics can be volatile. By establishing and upholding stringent regulatory standards, we can safeguard against the potential risks associated with nuclear energy while harnessing its vast potential for peaceful applications such as power generation, medical treatments, and scientific research. Central to this endeavor is cultivating a regulatory body that operates autonomously from political agenda, vested interests, or external pressures. Such independence is essential to maintain impartiality and integrity in decision-making processes related to nuclear safety, security, and nonproliferation measures.

Furthermore, an independent regulatory framework should be built on principles of transparency, accountability, and expertise. This entails ensuring that regulatory authorities have access to sufficient resources, including funding, technical expertise, and state-of-the-art technology, to carry out their mandate of oversight and enforcement effectively.

## 7. CONCLUSION

The current energy landscape in Africa highlights the critical need for alternative, sustainable energy sources to address pressing challenges. The discussion on small modular reactors within this context should focus on how SMRs can be integrated into Africa's energy transition, considering both the challenges and opportunities while maintaining a keen awareness of nuclear security and nonproliferation obligations. Due to the limited operational history of first-of-a-kind technology, it has become challenging to implement technology-specific safeguards to ensure nonproliferation, especially for Africa, where nuclear power operations are not predominant in many states. Notwithstanding, lessons learned from past and present operations of conventional reactors can serve as a baseline for managing security-related incidents. Promoting education and open dialogue on nuclear technology can go a long way in ensuring public trust in the industry. Establishing an independent regulatory framework instills confidence among stakeholders and the public and lays the foundation for responsible and sustainable development of nuclear energy in Africa and beyond. Through proactive regulation and diligent oversight, we can unlock the benefits of nuclear technology while mitigating potential risks, thereby contributing to advancing science, technology, and socioeconomic progress on the continent of Africa.

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